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Human-environment interaction during the Mesolithic- Neolithic transition in the NE Iberian Peninsula. Vegetation history, climate change and human impact during the Early-Middle Holocene in the Eastern Pre-Pyrenees

J. Revelles [a, *], F. Burjachs [b, c, d], A. Palomo [a], R. Piqué [a], E. Iriarte [e], R. Pérez-Obiol [f], X. Terradas [g]

[a] Departament de Prehistòria, Universitat Autònoma de Barcelona, 08193 Bellaterra, Spain
[b] ICREA, Pg. Lluís Companys 23, 08010 Barcelona, Spain
[c] Institut Català de Paleoecologia Humana i Evolució Social (IPHES), 43007 Tarragona, Spain
[d] Àrea de Prehistòria, Universitat Rovira i Virgili (URV), 43002 Tarragona, Spain
[e] Laboratorio de Evolución Humana, Departamento Ciencias Históricas y Geografía, Universidad de Burgos, Plaza Misael Bañuelos, Edificio I+D+i, 09001 Burgos, Spain
[f] Departament de Biologia Vegetal, de Biologia Animal i d'Ecologia, Unitat de Botànica, Universitat Autònoma de Barcelona, 08193 Bellaterra, Spain
[g] Archaeology of Social Dynamics, Institución Milà y Fontanals, Consejo Superior de Investigaciones Científicas (IMF-CSIC), C/Egipcíaques, 15, 08001 Barcelona, Spain

A R T I C L E I N F O

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A B S T R A C T

The synthetic analysis of several pollen records from sub-Mediterranean lowland Pre-Pyrenean regions evidences expansion of forests during the Early Holocene in Northeastern Iberia and the establishment of dense deciduous broadleaf forests during the Holocene Climate Optimum. Pollen records show the broadleaf deciduous forests resilience against cooling phases during the Mid-Holocene period, with slight regressions of oak woodlands and expansion of conifers or xerophytic taxa contemporary to some cooling episodes (i.e. 8.2 and 7.2 kyr cal. BP). Major vegetation changes influenced by climate change occurred in the transition to the Late Holocene, in terms of the start of a succession from broadleaf deciduous forests to evergreen sclerophyllous woodlands.

The lack of evidence of previous occupation seems to support the Neolithisation of the NE Iberian Peninsula as a result of a process of migration of farming populations to uninhabited or sparsely inhabited territories. In that context, remarkable changes in vegetation were recorded from 7.3 kyr cal. BP onwards in the Lake Banyoles area, where the establishment of permanent farming settlements caused the deforestation of oak woodlands. In La Garrotxa region, short deforestation episodes affecting broadleaf deciduous forests, together with expansion of grasslands and presence of Cerealia-t were documented in the period 7.4–6.0 kyr cal. BP. Finally, in the coastal area, where less evidence of Early Neolithic occupations is recorded, evidence of Neolithic impact is reflected in the presence of Cerealia-t in 6.5–6.2 kyr cal. BP, but no strong human transformation of landscape was carried out until more recent chronologies.

1. Introduction

Climate change has been widely proposed as a motor of social change, as the cause of crisis, migrations, abandonment and even collapse of past societies (Weiss et al., 1993; de Menocal, 2001; Weninger et al., 2006, 2009; Berger and Guilaine, 2009). Nevertheless, although abrupt climate change may influence social strategies or set constraints, human societies have always lived with a variable climate and have responded to it in different ways through the social organization, which should be understood as the product of the relationship between the environment and social

* Corresponding author.
E-mail address: jordi.revelles@gmail.com (J. Revelles).

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recognition of needs, and not a passive adaptation to a given framework. In that context, the study of climate fluctuations and ecological changes in the Early and Mid-Holocene becomes essential in order to assess the environmental framework and possible constraints during the Neolithisation process. Neolithisation involved changes in food production, management of resources and settlement patterns, deriving in economic, social and ecological transformations. Indeed, the adoption of the farming mode of production implied a new form of society-environment interaction and the onset of an increasing process of anthropisation and landscape transformation (Wright, 1971; Ruddiman, 2003; Ruddiman et al., 2015).

The various climatic fluctuations that occurred during the Holocene affected the development of vegetation (e.g. Burjachs et al., 2017). The establishment of a warmer and humid climate in the Early Holocene allowed the expansion of forests, specifically deciduous broadleaf forests, which was the dominant vegetation in the NE Iberian Peninsula in that period (Carrion et al., 2010; Pérez-Obiol et al., 2011). After the phase of maximum expansion of mesophilous forests during the Middle Holocene, a change from wetter to drier conditions is observed in the Mediterranean area in the transition to the Late Holocene (5.0–4.0 kyr cal. BP). This affected the vegetation with the expansion of the sclerophyllous Mediterranean forests (Jalut et al., 2000, 2009; Sadori and Narcisi, 2001; Roberts et al., 2001; Carrion et al., 2010; Pérez-Obiol et al., 2011). Nevertheless, the increasing trend of human impact from the Neolithic onwards means that the social management of resources should be included in the causes of vegetation changes. The adoption of farming practices resulted in the transformation of landscapes, as recorded in pollen records in the Mediterranean area (Riera and Esteban-Amat, 1994; Sadori and Narcisi, 2001; Yll et al., 2003; Drescher-Schneider et al., 2007; Colombaroli et al., 2008; Vannière et al., 2008; Kouli and Dermitzakis, 2008; Vescovi et al., 2010; Marinova et al., 2012).

The arrival of the first Neolithic groups in the Iberian Peninsula is dated to 7.65–7.6 kyr cal. BP, so this was the last region to adopt farming in the Mediterranean basin. However, although the evidence of deforestation during the early stages of Neolithisation in Iberia is often associated with farming activities, the low values or absence of Cerealia-t pollen and weeds in some sequences is noticeable (Carrión et al., 2007; Iriarte et al., 2007/2008; López-Sáez et al., 2007a, 2007b/2008; López-Merino, 2009; López-Merino et al., 2010; Pérez-Díaz et al., 2015). In that sense, the expansion of the first farming societies and the practice of an intensive agriculture implied limited impact on the landscape (Bogaard, 2004). Nevertheless, the establishment in permanent settlements and the practice of more intensive productive activities increasingly reiterated in the territory caused deforestation processes or, at least, small-scale forest modifications from the Neolithic onwards (Revelles, 2017).

This paper presents a synthesis of pollen records and the anthracological and archaeological record in the period 9.0–6.0 kyr cal. BP in order to characterize the Late Mesolithic-Early Neolithic transition and the environmental framework of this process in the Eastern Pre-Pyrenees (Catalonia, NE of Iberian Peninsula). The study area encompasses three regions: La Garrotxa, Pla de l'Estany and L'Empordà, thus constituting a longitudinal transect in the southern foothills of the Pyrenees, and offering the possibility of comparison with nearby lowland areas representing different bioclimatic and ecological contexts. The palaeoenvironment and climate evolution during the first half of the Holocene will be characterized and differences between the humid sub-Mediterranean inland and the Mediterranean coast will be assessed in terms of vegetation dynamics, settlement patterns and human impact.

The main objectives of this work are:

- To characterize the Late Mesolithic-Neolithic transition in the NE Iberian Peninsula
- To assess vegetation history, the influence of climate change and human impact in the eastern Pre-Pyrenees area during the Early to Middle Holocene.
- To assess human-environment relationships during the last hunter-gatherers – first farmers transition.

2. Study area

2.1. Environmental settings

2.1.1. Study area

The study area comprises the lowlands, valleys and plains located to the south of the eastern pre-Pyrenees, from altitudes of 0–500 m.a.s.l., but very close to mountains of 1000–1500 m.a.s.l. (Figs. 1 and 2). This work focuses on the north-eastern regions of Catalonia (La Garrotxa, Pla de l'Estany and Empordà). La Garrotxa is a mountainous region with a topography marked by deep valleys (lowlands at 250–300 m.a.s.l.) and steep mountainous areas (highest peaks at 1558 m.a.s.l.). To the east, Pla de l'Estany consists of a plain around Lake Banyoles (173 m.a.s.l.) surrounded by medium-height mountains (600–985 m.a.s.l.) and delimited by la Garrotxa to the west and l'Empordà basin to the east. In turn, l'Empordà consists of a wide plain located few metres above sea level with some low elevations and delimited to the north by the pre-Pyrenean Serra de l'Albera (800–1100 m.a.s.l.), to the south by Les Gavarres (350–530 m.a.s.l.) and to the east by the Mediterranean Sea. On the coast, some lagoons and wetlands resist in a strongly anthropised and urbanised area.

2.1.2. Climate

The climate in the NE Iberian Peninsula is defined as Mediterranean but with variations depending on the altitude and distance from the sea. Relief strongly influences the climate in this broad region and different sub-climates have been defined: littoral Mediterranean with low and irregular precipitations with a limited extent due to the presence of mountain ranges near and parallel to the coast; humid Mediterranean or sub-Mediterranean characterized by higher precipitation and cooler temperatures; and continental Mediterranean with low precipitation and contrasting temperatures, very warm in summer and cold in winter.

The topography of La Garrotxa represents an orographic barrier to humid and warm winds coming from the Mediterranean, which are forced to rise, causing high precipitation. The annual precipitation in La Vall d'en Bas (450–500 m.a.s.l.) is 1014 mm and the mean annual temperature is 13 °C. The average maximum temperature in summer is 21.6 °C and the minimum is 5.8 °C in winter. The climate in Pla de l'Estany (Lake Banyoles area) is defined as humid Mediterranean or sub-Mediterranean, with an annual precipitation of 750 mm and a mean annual temperature of 15 °C in Banyoles. The average maximum temperature during July and August is 23 °C, and the average minimum is 7 °C in winter. The climate in the coast is defined as Mediterranean with an annual precipitation of 580 mm and a mean annual temperature of 16 °C in Torroella de Montgrí. The average maximum temperature in summer is 23.6 °C and the average minimum is 9.2 °C in winter (Fig. 2).

2.1.3. Vegetation

At the present, the vegetation in the NE Iberian Peninsula is characterized by the predominance of evergreen sclerophyllous forests (evergreen oaks and Mediterranean pines) on the

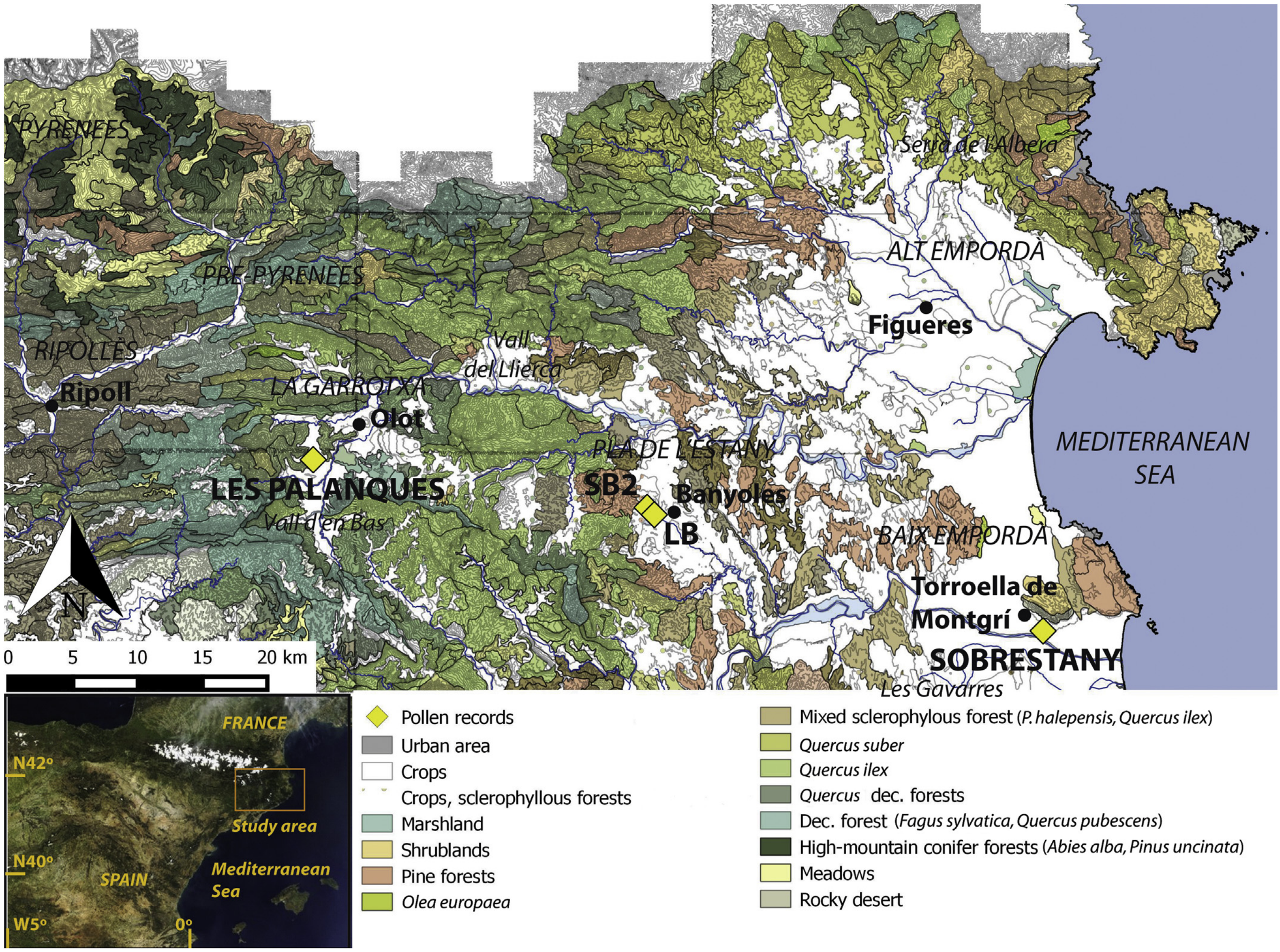

Fig. 1. Location of cores within the study area. Source for vegetation map: Mapa Forestal de España (Zona 10).

Mediterranean coast and in the continental interior; the presence of humid sub-Mediterranean forests (deciduous oak and beech) in the middle mountains in the pre-Pyrenees; and the presence of conifer forests in high mountain areas (Pyrenees) (Fig. 1).

The vegetation in La Vall d'en Bas (La Garrotxa) is characterized by the combination of several types of vegetation constituting a humid mountainous vegetation landscape. Beech (*Fagus sylvatica*) is found on mountain slopes, from 700 m.a.s.l. Nevertheless, when thermal inversion occurs, beech appears up to 500 m a.s.l. Oak forests of *Quercus robur* can be found in areas of wet and deep soil. Oak forests of *Quercus pubescens* are located on lowlands and sunny slopes. Finally, evergreen oaks (*Quercus ilex*) are located beneath the level of deciduous oaks, reaching 1000 m.a.s.l. in areas of high insolation or on rocky soils.

Pla de l'Estany consists of a transition area between humid forests in the mountainous area of La Garrotxa and the dominance of sclerophyllous trees on the coast. Dense vegetation formations in the mountains surrounding Lake Banyoles, are dominated by a mixed evergreen forest (*Quercus ilex*, *Quercus coccifera*, *Rhamnus alaternus*, *Phillyrea media*, *P. angustifolia*), deciduous oak (*Quercus pubescens*, *Buxus sempervirens*, *Ilex aquifolium*) and pine forest (*Pinus halepensis*). In this context, shrublands (*Erica arborea*, *Rosmarinus officinalis*) are well represented.

L'Empordà presents a very anthropogenic landscape with rice fields in the littoral wetlands and cereal crop fields in the drier soils of the inland plain, while hygrophyte communities (*Phragmites*, *Juncus*, *Typha*) and salt marshes (*Salicornia*) are limited to a local scale. At a regional scale, sclerophyllous forests are dominant due to their better adaptation to the summer dryness; *Quercus ilex* in calcareous mountains, *Quercus suber* on acidic and poor soils, and dominance of *Olea europaea, Phillyrea angustifolia* and *Pistacia lentiscus* and shrublands (*Erica arborea*, *Cistus monspeliensis*) in lowlands and in the littoral area.

2.2. Archaeological background

The transition from last hunter-gatherers in the Mesolithic to the first farming communities in the Neolithic has not attracted especial attention in research in the NE Iberian Peninsula (Oms et al., 2017), as opposed to neighbouring areas (Ebro basin, eastern coast of Iberia and Mediterranean coast of the French Midi). This situation is even more pronounced in the study area of the present work. The main reason is certainly the scarcity of archaeological records with evidence of occupations linked to this transition, in chronologies *ca.* 8400-7500 yr cal. BP (Fig. 3).

A few sites are remarkable in the study area for belonging to the last hunter-gatherer period, and sharing a similar geographic location. These are the rock shelter of Bauma del Serrat del Pont

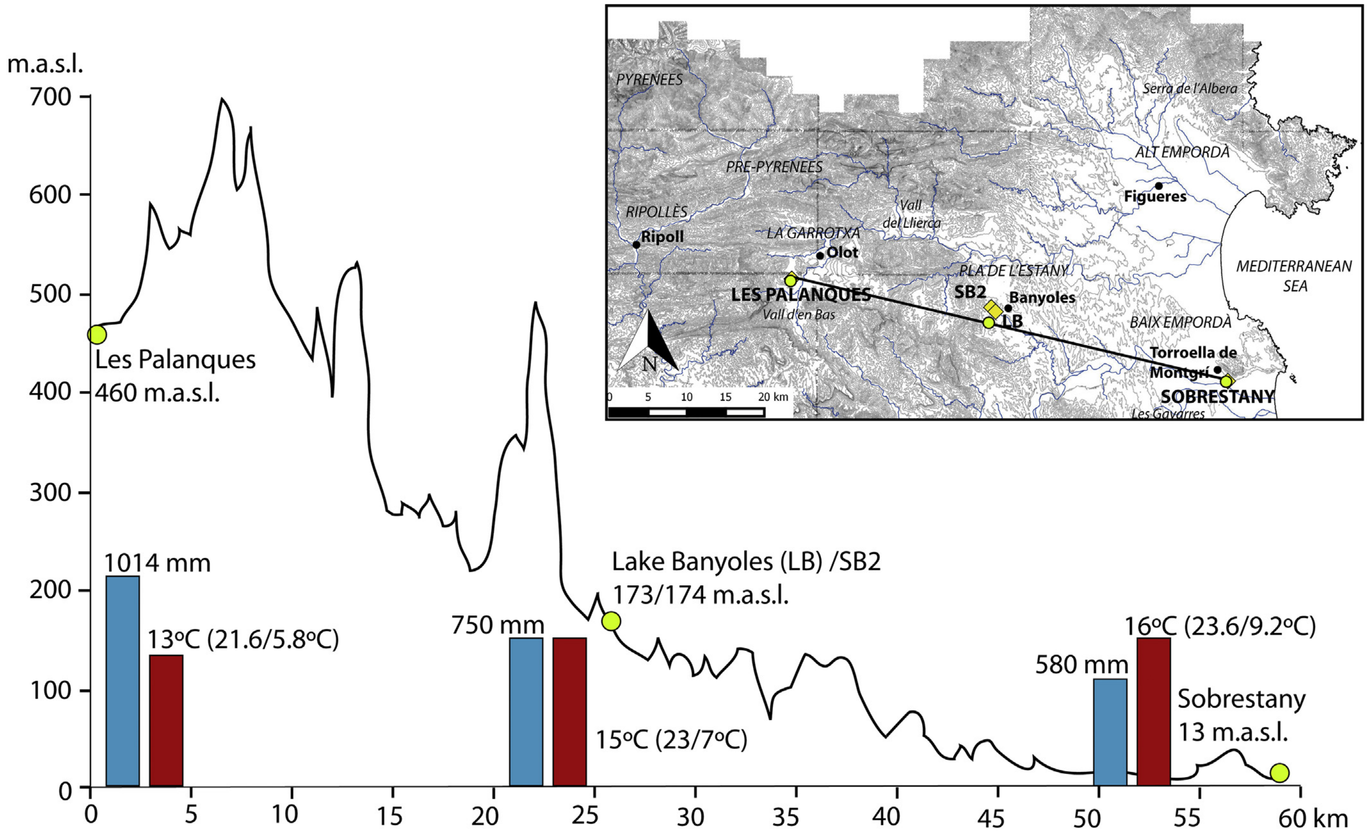

Fig. 2. Topographical transect and climogram (precipitation and temperature) in Vall d'en Bas (La Garrotxa), Banyoles (Pla de l'Estany) and Torroella de Montgrí (Baix Empordà).

(BSP) (9.4–8.0 kyr cal. BP; Tortellà, Girona) and the open-air settlement of Sota Palou (10.2–9.1 kyr cal. BP; Campdevànol, Girona) (CRPES, 1985; Alcalde and Saña, 2008). These were occupations in mid-mountain areas, in the contact between reliefs (Pre-Pyrenees) and plains near fluvial courses (Llierca river, tributary to Fluvià river, and Ter river, respectively, both following a Pyrenees-Mediterranean route and not connected to the Ebro basin). These areas were repeatedly occupied or for certain durations, with particular arrangements of the inhabited space, such as standing structures, hearths and pits filled with waste.

At an ecological level, they are located in ecotones or zones of contact between different biocenoses, which propitiates important resources variety that undoubtedly was exploited by the Mesolithic groups. The exploitation of lithic resources was carried out on an essentially local scale and aimed at the production of flakes, following different reduction schemes according to the nature and shape of the raw materials used, which in no case included a significant proportion of siliceous rocks (Terradas, 1998; Gibaja et al., 2005). These lithic products form assemblages characterized by tools made from flakes (mainly notches and denticulates), few blade blanks and the absence of geometrics. Therefore these assemblages are attributed to the technological tradition defined in the Iberian Peninsula as the “notches and denticulates Mesolithic” (Alday, 2006; Morales et al., 2013), which developed mainly in 9000–7800 cal. BP on the Mediterranean seaboard and in the Ebro basin.

However, some of the chronological sequences in the area of study had a longer duration and continued until a few centuries before the earliest Neolithic evidence is documented. This is the case of the levels dated in the Mesolithic occupations at Bauma del Serrat del Pont, which extend the use of this rock-shelter until the period 8.3-8-0 kyr cal. BP in stratigraphic unit IV.1 (Alcalde and Saña, 2008). This circumstance has also been documented at other sites in north-east Iberia, such as in Levels 19–20 (IVa) at Cova de Can Sadurni in Begues, in the Province of Barcelona (Fullola et al., 2011; Morales et al., 2012). In contrast, no evidence of the “geometric Mesolithic” (Utrilla and Montes, 2009), corresponding to the late Mesolithic, has been found in this area. This phase has only been documented in a few sequences in the southern part of the region, for example at Cova del Vidre in Roquetes (Bosch, 2015) and Coves del Fem in Ulldemolins (Palomo et al., 2017), both in the south of Tarragona and which seem to have been linked to the evidence in the Ebro basin. In consequence, with the most recent dates of Mesolithic sites in the area of study and in north-east Iberia as a whole, the evidence suggests a chronological hiatus of *ca.* 400–500 years, in approximately 8100–7600 yr cal. BP, in which no human occupations have been documented, until the arrival of the first signs of the so-called “Neolithic package” (Barceló, 2008; Vaquero and García-Argüelles, 2009; Morales et al., 2013; Oms et al., 2017).

Records attributable to the early Neolithic are more abundant than those of the late Mesolithic (as shown in Table 1). An overall assessment of the available radiocarbon dates for these occupations indicate that they can be distributed into four phases or chronological horizons (Oms, 2014): Phase 0 (*ca.* 7600-7400 yr cal. BP), Phase 1 (*ca.* 7450-7250 yr cal. BP), Phase 2 (*ca.* 7300-7100 yr cal. BP) and Phase 3 (*ca.* 7150-6800 yr cal. BP). No evidence seems to have been found of occupations attributed to Phase 0 in the area of study, as these are limited to littoral and pre-littoral areas of central and southern Catalonia (Oms et al., 2014). However, abundant evidence

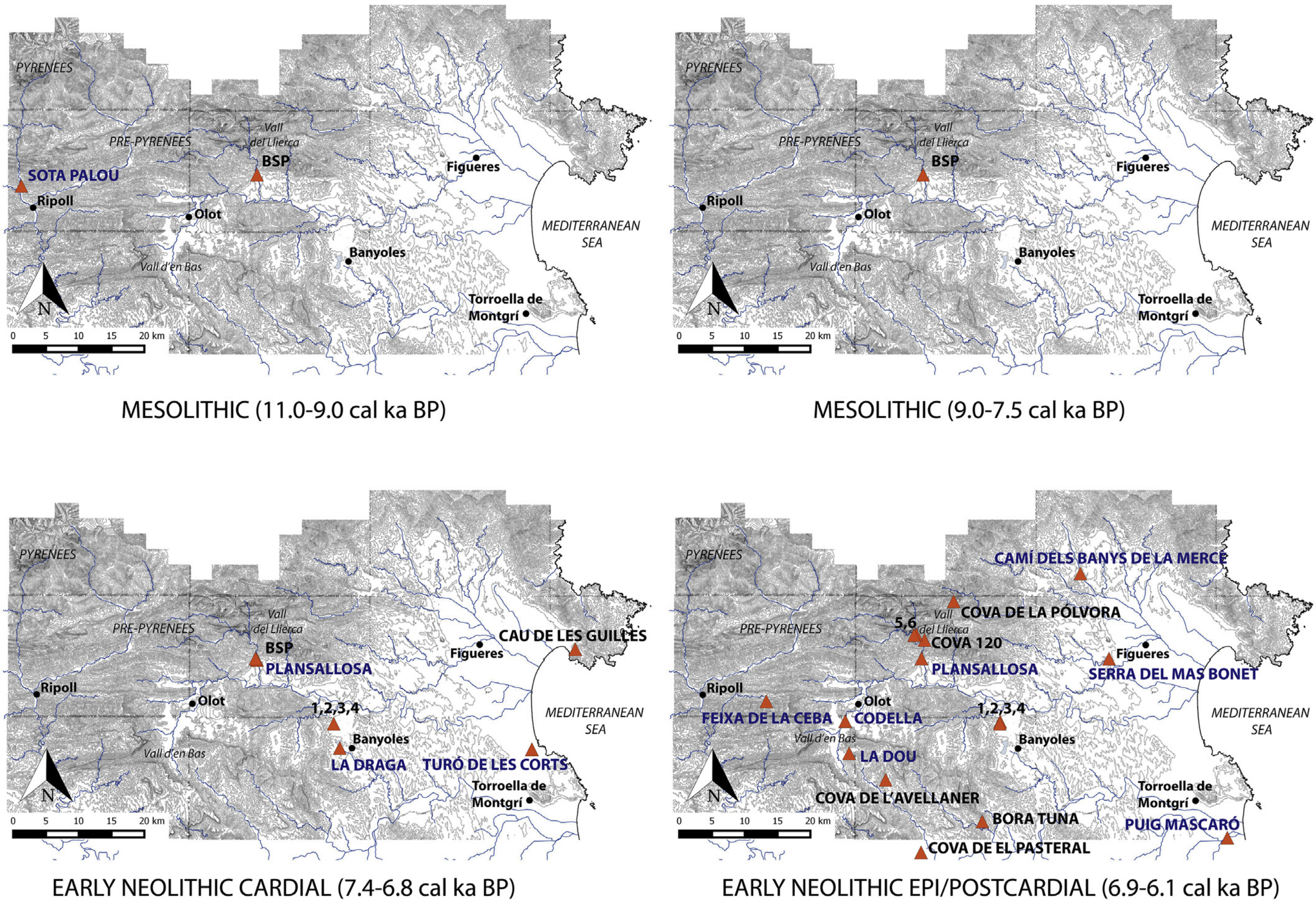

Fig. 3. Maps showing the distribution of archaeological sites in the study area in different chronocultural periods. Early Neolithic Cardial: 1) Cova d'en Pau, 2) Reclau Viver, 3) L'Arbreda, 4) Mollet III; EN Epi/Post-Cardial: 1) Cova d'en Pau, 2) Reclau Viver, 3) Cova Mariver, 4) Mollet III, 5) Cova del Bisbe, 6) Cova dels Ermitons. Open-air settlements in blue, cave occupations in black. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

has been found of the other phases, either directly through radiocarbon dating or indirectly by the ceramics associated with those chronological horizons.

In this study area, much of the earliest evidence of the effects of the Neolithic way of life has been found in coastal areas. However, these have been finds made in the course of highly biased archaeological research, due to the effect of building schemes in popular tourist areas or because such evidence was removed in the past by later occupations in prehistoric times and in Antiquity. These Neolithic settlements are located on plains or small hills near freshwater-courses, where land with agricultural potential was in the proximity of areas used for hunting, such as marshes or forests (Bosch, 1994). Some examples are Turó de les Corts (L'Escala) and Puig Mascaró (Torroella de Montgrí), open-air settlements near the mouths of the River Fluviá and Ter, respectively (Bosch, 1994), and Cau de las Guilles (Roses), a small rock-shelter by the coast (Soler and Serangeli, 2010). Isolated finds of cardial sherds (ca. 7.4–6.8 kyr cal. BP) have been found at these sites, although their contextualisation and chronological ascription is difficult for the reasons explained above.

Clear structuring of the terrain and occupation of large surface areas has been observed at the best-preserved sites. This is particularly the case of the settlement of La Draga, on the shore of Lake Banyoles (Girona), which is attributed to the Cardial Neolithic, and whose surface area is estimated to be over 10,000 m^2 (Bosch et al., 2000, 2011; Palomo et al., 2014). Two occupation phases have been documented at this site, linked to different building traditions. The oldest phase (7274-6950 yr cal. BP) is associated with structures built on wooden posts at the lakeside; and the second phase (7160-6930 yr cal. BP) with travertine slab pavements covering large areas and on which daily activities were performed. At the same time, rock-shelters and caves were used for different purposes, either as dwellings (Balma del Serrat del Pont; Alcalde et al., 2002) or possibly for mortuary uses, as may be the case of the series of caves at Serinyà (Arbreda, Mollet III, Pau and Reclau Viver), in Girona, where isolated human remains have been found. Although these appear in stratigraphic deposits, the later taphonomic processes they were subjected to hinder their chronological attribution (Tarrús, 2000).

Whereas at the more interior sites (Balma del Serrat del Pont) the exploitation of wild resources was significant (Alcalde et al., 2002), at the open-air sites (La Draga) the farming economy was well established, with agriculture based on varieties of free-threshing wheat (*Triticum aestivun/durum/turgidum*) (Antolín, 2016) and livestock consisting of ovicaprids, swine and cattle (Saña, 2011). These practices did not exclude the use of wild resources for very specific purposes (Antolín and Jacomet, 2015), although their contribution to the diet was very limited (Piqué et al., 2015).

The determination of the procurement areas of the different

Table 1
Archaeological sites from the Mesolithic to the Middle Neolithic in the eastern Pre-Pyrenees area. 'Ch' indicates archaeological sites providing anthracological data.

Site	Location	Region	Chronology (cal BP)	Period	Type	Ch.
Sota Palou	Campdevànol	Ripollès	10,154–9094	Mesolithic	Open-air	X
Font del Ros	Berga	Berguedà	9401–8555	Mesolithic	Open-air	X
BSP IV.5	Tortellà	La Garrotxa	9447–9141	Mesolithic	Cave	X
BSP IV.4			9242–8997	Mesolithic		X
BSP IV.3			9090–8775	Mesolithic		X
BSP IV.2			8632–8430	Mesolithic		X
BSP IV.1			8284–8021	Mesolithic		X
BSP III.4			7430–7330	Early Neol. Cardial		X
Plansallosa	Tortellà	La Garrotxa	7200–6860	Early Neol. Cardial	Open-air	X
La Draga	Banyoles	Pla Estany	7270–6750	Early Neol. Cardial	Open-air	X
Cova d'en Pau	Serinyà	Pla Estany	*ca.* 7.4–6.8	Early Neol. Cardial	Cave	
Mollet III	Serinyà	Pla Estany	*ca.* 7.4–6.8	Early Neol. Cardial	Cave	
Reclau Viver	Serinyà	Pla Estany	*ca.* 7.4–6.8	Early Neol. Cardial	Cave	
L'Arbreda	Serinyà	Pla Estany	*ca.* 7.4–6.8	Early Neol. Cardial	Cave	
Cau de les Guilles	Roses	Alt Empordà	*ca.* 7.4–6.8	Early Neol. Cardial	Cave	
Turó de les Corts	L'Escala	Alt Empordà	*ca.* 7.4–6.8	Early Neol. Cardial	Open-air	
Feixa de la Ceba	Vallfogona de Ripollès	Ripollès	*ca.* 6.5–6.1	Early Neol. Epicardial/Postcardial	Open-air	
Codella	Vall d'en Bas	La Garrotxa	6660–6520	Early Neol. Epicardial/Postcardial	Open-air	X
La Dou	Vall d'en Bas	La Garrotxa	6560–6213	Early Neol. Epicardial/Postcardial	Open-air	X
Cova de l'Avellaner	Les Planes d'Hostoles	La Garrotxa	6883–6410	Early Neol. Epicardial/Postcardial	Cave	X
Plansallosa	Tortellà	La Garrotxa	*6850–6375*	Early Neol. Epicardial	Open-air	
Cova 120	Sales de Llierca	La Garrotxa	*ca.* 6.9–6.1	Early Neol. Epicardial/Postcardial	Cave	X
Cova s'Espasa	Montagut i Oix	La Garrotxa	*ca.* 6.9–6.1	Early Neol. Epicardial	Cave	
Cova dels Ermitons	Sales de Llierca	La Garrotxa	*ca.* 6.9–6.1	Early Neol. Epicardial	Cave	
Cova d'en Pau	Serinyà	Pla Estany	6883–6410	Early Neol. Epicardial	Cave	X
Mollet III	Serinyà	Pla Estany	*ca.* 6.9–6.1	Early Neol. Epicardial	Cave	
Reclau Viver	Serinyà	Pla Estany	*ca.* 6.9–6.1	Early Neol. Epicardial	Cave	
Cova Mariver	Esponellà	Pla Estany	*ca.* 6.9–6.1	Early Neol. Epicardial	Cave	
Bora Tuna	St. Martí de Llèmena	Gironès	*ca.* 6.9–6.1	Early Neol. Epicardial	Cave	
Cova de El Pasteral	La Cellera de Ter	Gironès	*ca.* 6.9–6.1	Early Neol. Epicardial	Cave	
Camí dels Banys de la Mercè	Capmany	Alt Empordà	*ca.* 7.1–6.9	Early Neol. Epicardial	Open-air	
Serra del Mas Bonet	Vilafant	Alt Empordà	*ca.* 6.9–6.6	Early Neol. Epicardial	Open-air	X
Puig Mascaró	Torroella de Montgrí	Baix Empordà	*ca.* 6.9–6.6	Early Neol. Epicardial	Open-air	
Cova del Bisbe	Sadernes	La Garrotxa	*ca.* 6.1–5.4	Early Neol. Postcardial	Cave	
Cova d'en Pau	Serinyà	Pla Estany	*ca.* 6.1–5.4	Early Neol. Postcardial	Cave	
Cova Mariver	Esponellà	Pla Estany	*ca.* 6.1–5.4	Postcardial/Middle Neolithic	Cave	
Cova de la Pólvora	Albanyà	Alt Empordà	*ca.* 6.1–5.4	Early Neol. Postcardial	Cave	
Cova de El Pasteral	La Cellera de Ter	Gironès	*ca.* 6.1–5.4	Early Neol. Postcardial	Cave	
Serra del Mas Bonet	Vilafant	Alt Empordà	*ca.* 6.1–5.4	Middle Neolithic	Open-air	X
Ca n'Isach	Palau-Saverdera	Alt Empordà	5994–5599	Middle Neolithic	Open-air	X

resources is able to reveal numerous contacts with neighbouring areas and settlements, located in several directions and of varying intensity. Therefore, a wide range of technical knowledge and traditions was shared with them (Terradas et al., 2012).

From these first sites, the consolidation of the new subsistence practices inherent in the Neolithic economy spread rapidly across the study area in during the phases that are known as the "Epicardial" (*ca.* 6.9–6.5 kyr cal. BP) and "Postcardial" (*ca.* 6.5–6.1 cal ka BP) (Epi/Postcardial in Fig. 3). As a result, the sites become more abundant and correspond to greater specialisation in the occupations. In this way, they include open-air settlements like Plansallosa (Tortellà), La Dou and Codella (Vall d'en Bas), la Serra del Mas Bonet (Vilafant) and Camí dels Banys de la Mercè (Capmany) (Agustí et al., 1987; Bosch et al., 1998; Alcalde et al., 2009, 2012, 2014; Rosillo et al., 2012); dwellings in caves and rock-shelters like Cova Mariver (Tarrús, 2000); as well as other functions that may have been complementary to the above: storage areas for farm products like Cova 120 (Agustí et al., 1987) and Cova de la Pólvora (Buch et al., 1996). In other cases, caves were used for mortuary purposes, as at les Encantades de Martís (Esponellà), Els Encantats and Cova Mariver (Esponellà), Bora Tuna (Llorà), El Pasteral (La Cellera de Ter), la Cova de la Pólvora (Albanyà) and above all at Cova de l'Avellaner (Planes d'Hostoles), where human remains belonging to a minimum number of 19 individuals were found, corresponding to primary and secondary burials (Bosch, 1994; Bosch and Tarrús, 1990; Lacan et al., 2011).

3. Material and methods

3.1. Pollen records

3.1.1. Les Palanques (Vall d'en Bas, La Garrotxa, 460 m.a.s.l.)

The Les Palanques core was taken in a former lacustrine area, nowadays a crop field plain. La Vall d'en Bas is located in the south-western part of La Garrotxa (Girona, Spain) (Fig. 1), with an area of 90.82 km^2. It consists of a tectonic trench in a complex fault system, displaying clear differentiation between the plain (mean altitude of 510 m.a.s.l.) and the mountainous area (highest peaks of 1515 m.a.s.l.). La Vall d'en Bas is located to the south of the volcanic area of La Garrotxa; it is drained by the Fluvià river and three tributaries: Ridaura, Joanetes and San Privat, and is a product of successive obstructions of the river by Quaternary basaltic flows (Cros et al., 1986; Puiguriguer et al., 2012; de Bolòs et al., 2014). The core was 860 cm deep with a total of 3 radiocarbon dates at 240, 640 and 750 cm (Table 2). Asteraceae liguliflorae (Cichorioideae) was excluded from the Pollen Sum given its overrepresentation in soil erosion/edaphisation processes.

3.1.2. Lake Banyoles (Banyoles, Pla de l'Estany, 173 m.a.s.l.)

The Lake Banyoles core was obtained from the eastern shore of the lake. The study site is located 35 km from the Mediterranean Sea and 50 km south of the Pyrenees (Fig. 1). Lake Banyoles is a karst lake associated with a large karst aquifer system located in a

Table 2
Radiocarbon dating results.

Sample depth (cm)	Material	Radiocarbon date BP	cal. year BP (2σ range)	cal. yr BP in diagram
Les Palanques				
240	Peat	2330 ± 65	2700–2223	2417
640	Peat	7340 ± 80	8254–7896	8091
750	Bulk sed.	8380 ± 80	9571–9282	9421
Lake Banyoles (LB)				
80	Peat	5794 ± 60	6734–6454	6703
210	Peat	6417 ± 90	7485–7167	7977
500	U/Th	9664 ± 190	10,035–9292	9883
590	U/Th	11,410 ± 100	11,605–11215	11,315
Banyoles (SB2)				
173	Bulk sed.	2590 ± 30	2876–2732	2759
201	Charcoal	4480 ± 30	5171–4836	5030
215	Bulk sed.	4650 ± 30	5452–5292	5383
237	Bulk sed.	5148 ± 30	6239–5948	6024
253	Bulk sed.	6645 ± 31	7518–7171	7418
276	Bulk sed.	7855 ± 30	8947–8609	8685
Sobrestany				
220	Bulk sed.	1350 ± 30	1311–1186	1269
330	Bulk sed.	1525 ± 30	1522–1348	1436
500	Bulk sed.	2310 ± 50	2463–2155	2335
590	Bulk sed.	3095 ± 35	3380–3218	3280
1100	*Cardium*	5240 ± 70	6261–5894	6039
1300	*Cardium*	5780 ± 410	7468–5754	6621

tectonic depression, fed by underground water. The lake is approximately 2100 m long and 750 m wide with an average depth of 15 m that in several places reaches up to 46 m (Casamitjana et al., 2006; Höbig et al., 2012). The core is 3310 cm length, providing a continuous pollen record for the last 30,000 years. Nevertheless, in this work we will focus on the Holocene part of the sequence, which is the first 620 cm. The four dates obtained were located at 80, 210, 500 and 590 cm. Aquatic and hygrophyte taxa were excluded to avoid over-representation by local taxa.

3.1.3. SB2 (Banyoles, Pla de l'Estany, 174 m.a.s.l.)

The SB2 core was obtained from the western shore of Lake Banyoles, 160 m away from the present lakeshore. It consists of a 370 cm long core, with a continuous analysed pollen record of 107 cm (organic facies between 174 and 281 cm depth). The six dates obtained were located at 173, 201, 215, 237, 257 and 276 cm. *Typha latifolia*, *Typha/Sparganium* and *Alnus* were excluded from the pollen sum to avoid over-representation by local taxa.

3.1.4. Sobrestany (Torroella de Montgrí, Baix Empordà, 13 m.a.s.l.)

The Sobrestany core was drilled in a former lagoon area, which is now rice fields, in a fluvial floodplain of 1285 km^2 (Fig. 1), delimited to the north by the eastern Pyrenees, to the south by Les Gavarres mountain range and to the east by the Mediterranean Sea. The plain is surrounded by mountains of 400–500 m.a.s.l. This lacustrine system is fed by the inputs of the Fluvià River and depends on the consolidation of the coast, thus providing a continuous sedimentation since the Middle Holocene onwards (Parra et al., 2005). The core was 1900 cm deep, with hiatuses in the bottom of the sequence but providing a continuous pollen record of 1665 cm. A total of six radiocarbon dates were carried out at 220, 330, 500, 590, 1100 and 1300 cm (Table 2). Amaranthaceae-Chenopodiaceae was excluded from the Pollen Sum given its overrepresentation in a salt marsh environment.

3.2. Anthracological record

Charcoal data come from 12 sites: 2 with Mesolithic occupations, 9 with Neolithic levels and one with a long sequence covering from Mesolithic to Bronze Age occupations (Fig. 9). All data have been published independently and some of them have been the object of partial summaries in several publications, albeit only focused on specific chronologies (Piqué, 2005; Ros, 1996) or regions (Piqué et al., 2017). Most of the sites are located in La Garrotxa, Pla de l'Estany and Empordà. However in order to obtain a wider sample of Mesolithic layers we have also included data from two sites in the neighbouring areas of Berguedà and Ripollès. The sites are dated between 10.0 and 6.0 kyr cal. BP. The sample comprises 7426 charcoal fragments.

The site of Sota Palou (CRPES, 1985) is the earliest Mesolithic level with studied charcoal remains. The site, located at Campdevànol corresponds to a single open-air occupation dated to 10,154–9094 yr cal. BP. A sample of 96 fragments of charcoal was studied. The second site is Font del Ros, located at Berga (Jordà et al., 1992), corresponding to an open-air settlement with Neolithic and Mesolithic occupations. Only the charcoal from the Mesolithic has been studied to date. This occupation is dated in 9401–8555 yr cal. BP. The site has provided a significant amount of charcoal material, and a sample of 1191 fragments has been analysed.

The longest sequence is from the site of Bauma del Serrat del Pont, the only multilayer site in the region with occupations dated from the Mesolithic to the Bronze age. In this paper only the five Mesolithic (9.4–8.0 kyr cal. BP) and one early Neolithic (7.4–7.3 kyr cal. BP) layers are included (Alcalde et al., 2002; Alcalde and Saña, 2008). The studied sample consists of 1211 fragments of charcoal.

Among the Neolithic sites, six correspond to open-air settlements: Plansallosa (Bosch et al., 1998), La Dou (Alcalde et al., 2012, 2014) and Codella (Alcalde et al., 2009) located in La Garrotxa, La Draga (Pla de l'Estany) (Bosch et al., 2000), Serra del Mas Bonet (Rosillo et al., 2012) and Ca n'Isach (Empordà) (Tarrús et al., 1992) (Table 1). A sample of 380 fragments of charcoal from the open-air settlement of Plansallosa, dated to 7251-6939 yr cal. BP, has been studied. Two more open-air sites have provided charcoal data: Codella dated in 6660–6520 yr cal. BP, with a small sample of charcoal (N = 83) and the early Neolithic occupation of La Dou, dated in 6560–6213 yr cal. BP with 212 charcoal fragments. The site of La Draga, an open-air settlement located on the shore of Lake Banyoles (Pla de l'Estany), has provided the largest sample in the two occupation phases documented, as stated above. In this site, a

sample of 3103 fragments of charcoal has been studied. In Empordà, the site of Serra del Mas Bonet has provided evidence of two Neolithic phases (Rosillo et al., 2012); the earliest is dated in 6850–6550 cal. BP and the youngest in 6050–5350 yr cal. BP. A sample of 76 charcoal fragments has been studied. The site of Ca n'Isach (Tarrús et al., 1992) has provided a sample of 433 fragments of charcoal from the middle Neolithic occupation dated in 5994–5599 yr cal. BP.

Finally, three caves with different functions, two of them funerary (Cova d'en Pau, Cova de l'Avellaner) and the other related to storage activities (Cova 120) have been analysed. In Cova d'en Pau (Tarrús and Bosch, 1990) a sample of 258 fragments of charcoal has been studied, dated in 6843–5993 yr cal. BP. In Cova de l'Avellaner (Bosch and Tarrús, 1990), dated in 6883–6410 yr cal. BP, the sample is smaller, only 117 fragments, while in Cova 120 the sample consists of 207 pieces of charcoal. Although the site is not radiocarbon-dated, preliminary radiometric research and the pottery decoration allows this occupation to be related to the Epicardial Neolithic (*ca*. 6.9–6.5 kyr cal. BP).

3.3. Age-depth models

Pollen records covering the Holocene have been selected: Les Palanques (9.75 kyr cal. BP- Present) in La Vall d'en Bas (La Garrotxa) (Pérez-Obiol, 1988), Lake Banyoles (11.7–6.1 kyr cal. BP) and SB2 (8.9–3.35 kyr cal. BP) in Banyoles (Pla de l'Estany) (Pérez-Obiol and Julià, 1994; Revelles et al., 2014, 2015) and Sobrestany (7.7 kyr cal. BP- Present) in Torroella de Montgrí (Baix Empordà) (Parra et al., 2005). The age-depth models are based on radiocarbon dates (see Table 2) and calibration to years cal BP was made using Clam 2.2. (Blaauw, 2010) based on the data set IntCal13.14C (Reimer et al., 2013). The age-depth model was built using the smooth spline interpolation method (Fig. 4) and it was used to plot the data (Figs. 5–8, 10 and 11). In Les Palanques core, the pollen diagram was plotted by depth (Fig. 5) due to low robustness of the age-depth model and presence of hiatuses and edaphisation processes.

4. Results

4.1. Pollen records

4.1.1. Les Palanques (Vall d'en Bas, La Garrotxa, 460 m.a.s.l.)

The sequence from Les Palanques (La Garrotxa) provides pollen data to reconstruct the vegetation history of the last 10,100 years. An expansion of forests occurred during the early Holocene, dominated by *Pinus* sp., and deciduous forests, mainly deciduous *Quercus* and *Corylus avellana,* but also *Tilia*, *Acer* and *Buxus* (Fig. 5). The deciduous forest optimum occurred about 8.0–5.5 kyr cal. BP. In that sense, the landscape that the first farming communities found on their arrival in the region consisted of dense broadleaf deciduous forests, pine forests in the mountains and riparian forests (*Salix*, *Ulmus*, *Alnus*) on riverbanks and lakeshores. Then, from 5.0 kyr cal. BP onwards, deciduous oak and hazel display a regression, contrasting with an expansion of *Quercus ilex-coccifera* and *Pinus* sp. This process of succession from deciduous to evergreen forests was completed in historical times.

4.1.2. Lake Banyoles (Banyoles, Pla de l'Estany, 173 m.a.s.l.)

Although Lake Banyoles sequence provides pollen data since 30.0 kyr cal. BP (for more details on Pleistocene vegetation see Pérez-Obiol and Julià, 1994), this work will focus on Early and Mid-Holocene vegetation (11.7–6.1 kyr cal. BP). This sequence shows the expansion of forests from the beginning of the Holocene with a decreasing trend of grasslands that formed steppes in the Late Glacial period (Pérez-Obiol and Julià, 1994). *Pinus*, *Betula,* cf. *Juniperus* and *Acer* played the leading role in the first expansion of forests in 11.7–9.5 kyr cal. BP (Fig. 6). After 9.5–9.0 kyr cal. BP the expansion of forests was completed, reaching 90% of AP, now with the expansion and the onset of the dominance of broadleaf deciduous trees, mainly deciduous *Quercus* and *Corylus*. In that sense, the deciduous forest optimum occurred about 9.0–7.6 kyr cal. BP, although it may be expanded until the end of the sequence (6.1 kyr cal. BP), after some centuries of regression of oak forests.

The start of the regression of deciduous *Quercus* occurred about 8.2 kyr cal. BP and was consolidated after 7.6–7.4 kyr cal. BP. This oak forest regression coincides with the expansion of *Abies*, which appeared in the area in *ca.* 8.5 kyr cal. BP and with its maximum values in the phase 8.0–6.6 kyr cal. BP. When the first farming societies reached the Lake Banyoles area (7.4–7.0 kyr cal. BP) a slight expansion of Poaceae, *Artemisia,* Asteraceae and *Plantago* is attested in the context of episodes of expansion/regression of the oak forest.

4.1.3. SB2 (Banyoles, Pla de l'Estany, 173 m.a.s.l.)

The SB2 sequence from Lake Banyoles provides a pollen record covering the whole Mid-Holocene (8.2–4.2 kyr cal. BP). From its start, this sequence shows the dominance of broadleaf deciduous forests coinciding with the optimum evidenced in the Lake Banyoles sequence from 9.0 kyr cal. BP onwards. Despite showing episodes and phases of oak forest regression in 7.25–5.55 kyr cal. BP, coinciding with the establishment of the first Neolithic communities in the area, the optimum of broadleaf deciduous forests is maintained until the end of the sequence, indicating a persistence of oak forests until the onset of the Late Holocene. The oak decline coincides with an expansion of secondary trees such as *Pinus* or *Tilia* and grasslands (Fig. 7). Also noteworthy is the first arrival of *Abies* to the area in 8.5–8.0 kyr cal. BP, appearing with a continuous curve after 7.6 kyr cal. BP, thus coinciding with the Lake Banyoles sequence.

4.1.4. Sobrestany (Torroella de Montgrí, Baix Empordà, 13 m.a.s.l.)

The age-depth model, based on six AMS radiocarbon dates and built using smooth spline interpolation, places the Sobrestany sequence between 7.7 kyr cal. BP and the present (Fig. 8), thus providing a pollen record for the Middle and Late Holocene. After episodes of erosion at the bottom of the sequence, from 7.7 kyr cal. BP onwards a phase of sedimentation starts in a lacustrine environment without signs of erosion. The maximum expansion of broadleaf deciduous forests is recorded in 7.7–5.5/5.3 kyr cal. BP, coinciding with the highest values of AP in the sequence (>90%). After 5.5 kyr cal. BP, an alternation between lacustrine and lagoon phases occurred, coinciding with a decline of deciduous *Quercus* and *Corylus* and a progressive expansion of evergreen *Quercus* and *Pinus*. First evidence of Cerealia-t is documented in 6.7 and in 6.3 kyr cal. BP, coinciding with a regression of deciduous *Quercus* and a slight decrease in AP. *Abies* is present with a continuous curve from the beginning of the sequence and *Fagus* appears intermittently in 7.5–6.5 kyr cal. BP and with a continuous curve after 6.0 kyr cal. BP, indicating an earlier appearance of these taxa when compared with the inland sub-Mediterranean area. Also remarkable is the early appearance and continuous curve with high values of *Alnus* from the beginning of the sequence.

4.2. Charcoal record

4.2.1. Sota Palou (Mesolithic, 10.2–9.1 kyr cal. BP)

The site of Sota Palou (CRPES, 1985) is characterized by the dominance of *Pinus* t. *sylvestris-nigra*. It is the only Holocene layer in the sample where *Pinus* is the dominant taxa. Nevertheless, the presence of *Corylus avellana* and deciduous *Quercus* is noteworthy.

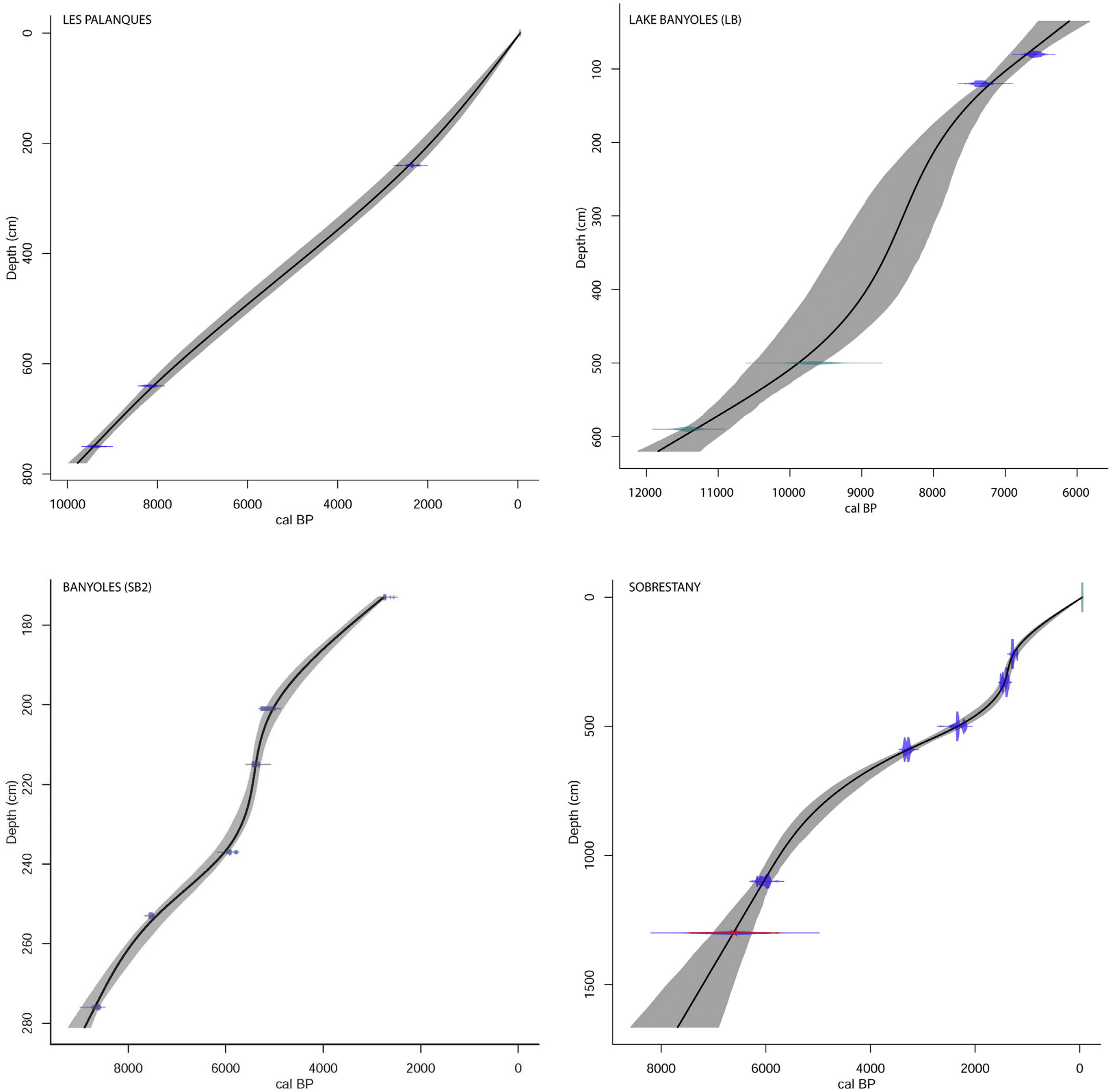

Fig. 4. Age-depth models of the studied cores based on AMS radiocarbon dates. Estimation along the entire profiles by a smooth spline technique using Clam 2.2 (Blaauw, 2010).

4.2.2. Font del Ros (Mesolithic, 9.4–8.6 kyr cal. BP)

In the site of Font del Ros *Quercus* sp. deciduous was the most abundant taxa, although *Corylus avellana*, *Buxus sempervirens* and Rosaseae/Maloideae were also intensively used. Although *Pinus* was still used as firewood, its presence is minimal, which suggests a minor role in the surroundings of the site at this time. The results confirm the presence of a deciduous forest in the area, formed by oak, boxwood, maple, hazel, Rosaceae/Maloideae and *Prunus* (Jordà et al., 1992).

4.2.3. Bauma del Serrat del Pont (Mesolithic, 9.4–8.0 kyr cal. BP; early Neolithic, 7.4–7.3 kyr cal. BP)

The long sequence at Bauma del Serrat del Pont allows the documentation of changes in the use of firewood in this period (Piqué, 2002). In the Mesolithic layers, *Quercus* sp. deciduous is always the most used taxon. However, some differences are documented. The two oldest levels are represented by a small amount of charcoal, so the results should be interpreted carefully. However, the most significant taxa documented in the other layers are represented here: deciduous *Quercus* and *Buxus sempervirens*.

In the next Mesolithic layers, it is interesting to highlight the importance of *Quercus* sp. deciduous and its decrease in favour of *Buxus*. The lowest *Quercus* values are documented in the layer dated at 8284-8021 cal BP. The almost total absence of *Corylus* is also noticeable. Other taxa like *Pinus*, *Acer* and Rosaceae/Maloideae are always present in low frequencies.The only early Neolithic layer

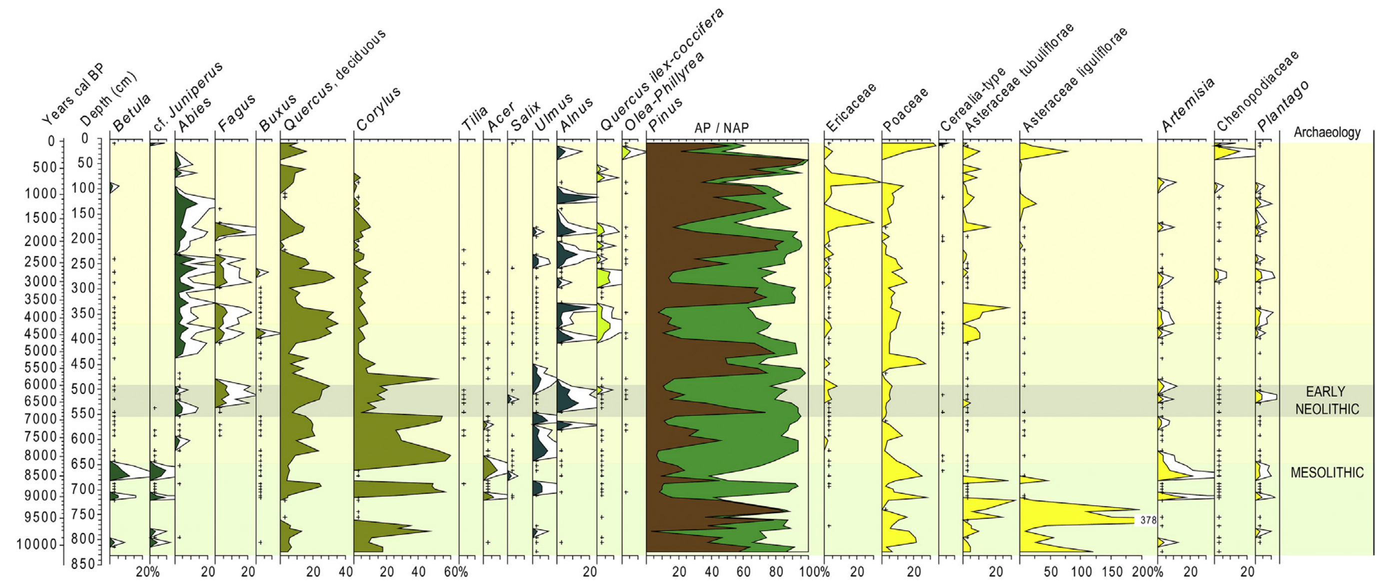

Fig. 5. Percentage pollen diagram. Selected pollen taxa from Les Palanques core (La Vall d'en Bas) are plotted to a depth (cm) scale. Hollow silhouettes show values multiplied x3. Values below 1% are represented by crosses.

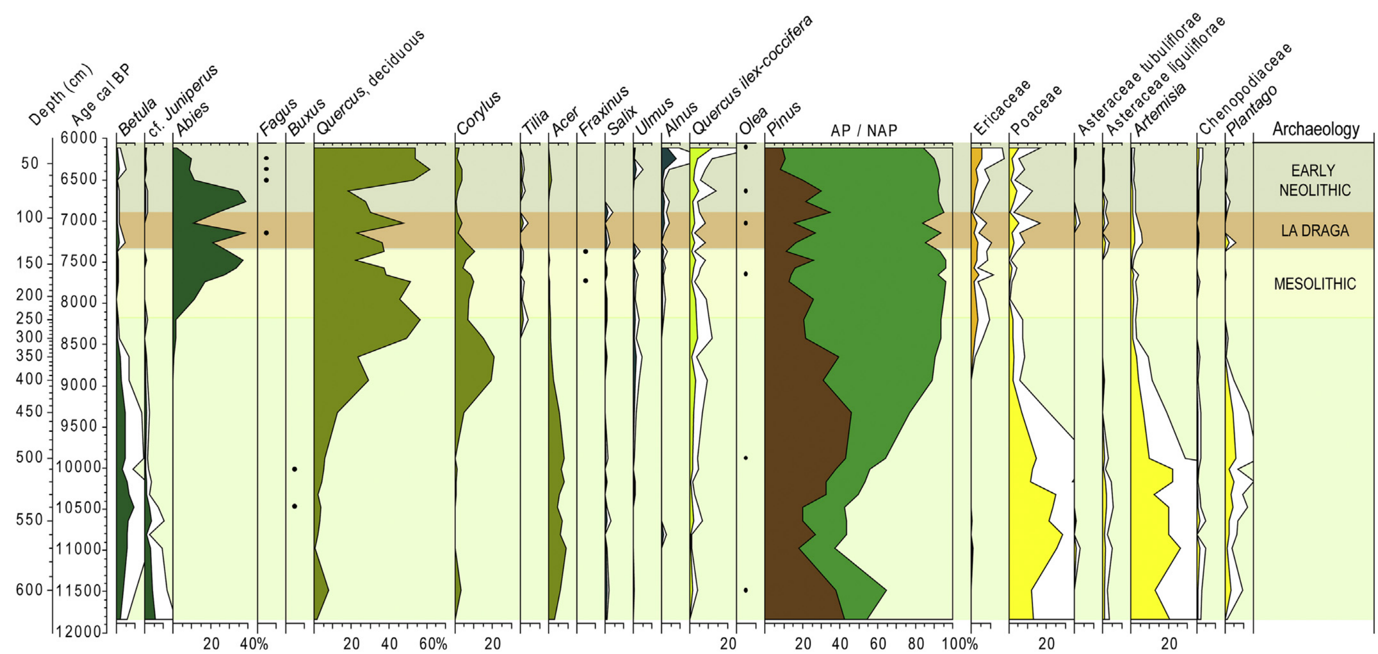

Fig. 6. Percentage pollen diagram. Selected pollen taxa from Lake Banyoles core (Banyoles) are plotted to a calibrated year BP scale. Hollow silhouettes show values multiplied x3. Values below 1% are represented by dots (also in Figs. 7–9).

documented at the site shows a similar composition to that observed in the most recent Mesolithic layer.

4.2.4. La Draga (early Neolithic, 7.3–6.7 kyr cal. BP)

The charcoal from the two occupation phases at La Draga has provided a similar taxonomic composition (Caruso-Fermé and Piqué, 2014). *Quercus* sp. deciduous is the dominant taxa, but the presence of *Laurus nobilis*, other riparian and deciduous taxa like *Corylus*, *Ulmus*, *Vitis* or Salicaceae is also important. Among Mediterranean taxa, *Arbutus unedo* and *Quercus ilex-coccifera* are present in very low frequencies, and *Quercus ilex-coccifera* is only documented in the earliest phase. The increase in *Buxus* in the late phase is noteworthy. The presence of conifers is testimonial; only *Taxus baccata* is present in both phases while *Pinus sylvestris-nigra* and *Juniperus* appear in only one of them.

4.2.5. Plansallosa (early Neolithic, 7.2–6.9 kyr cal. BP)

The dominant taxon in the site of Plansallosa is *Quercus* sp. deciduous (70% of the remains), but the presence of *Buxus sempervirens* and *Quercus ilex-coccifera* (Ros, 1998) is also significant. Other deciduous taxa like maple, Rosaceae/Maloideae and hazel are also documented. *Pinus* t. *sylvestris/nigra* and *Taxus baccata* are present in very low frequencies.

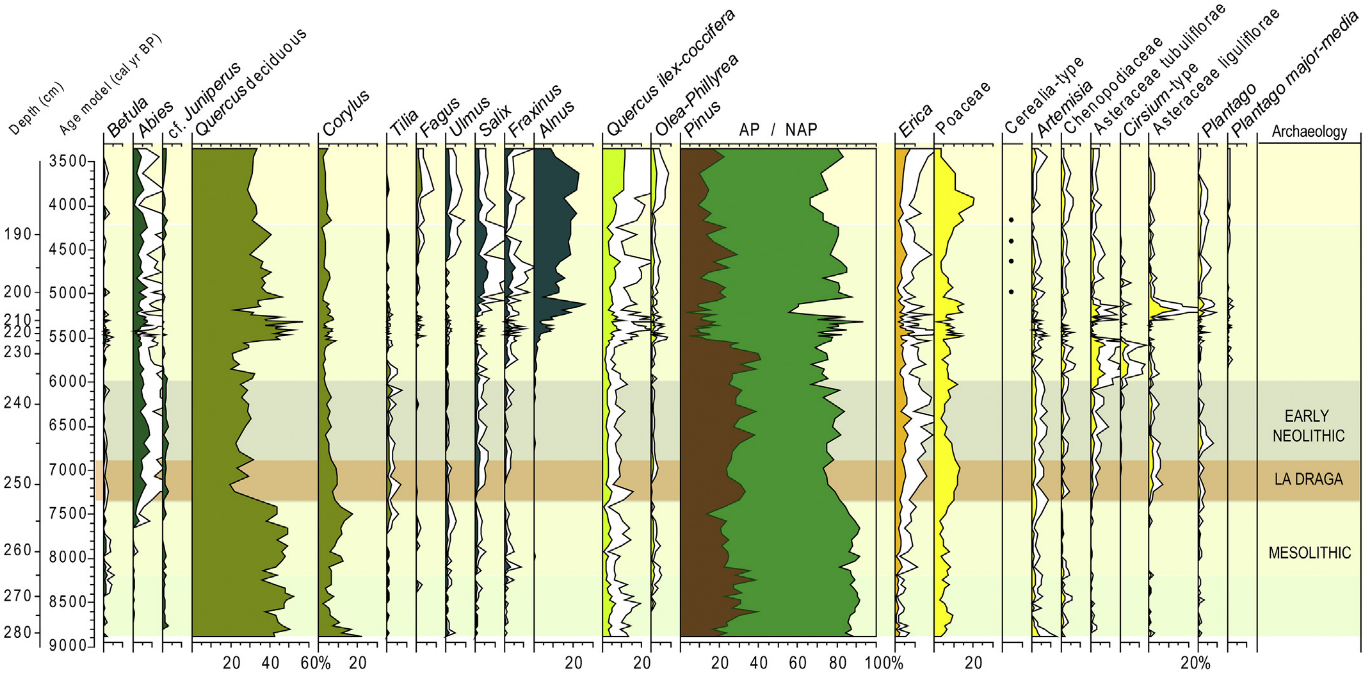

Fig. 7. Percentage pollen diagram. Selected pollen taxa from SB2 core (Banyoles) are plotted to a calibrated year BP scale.

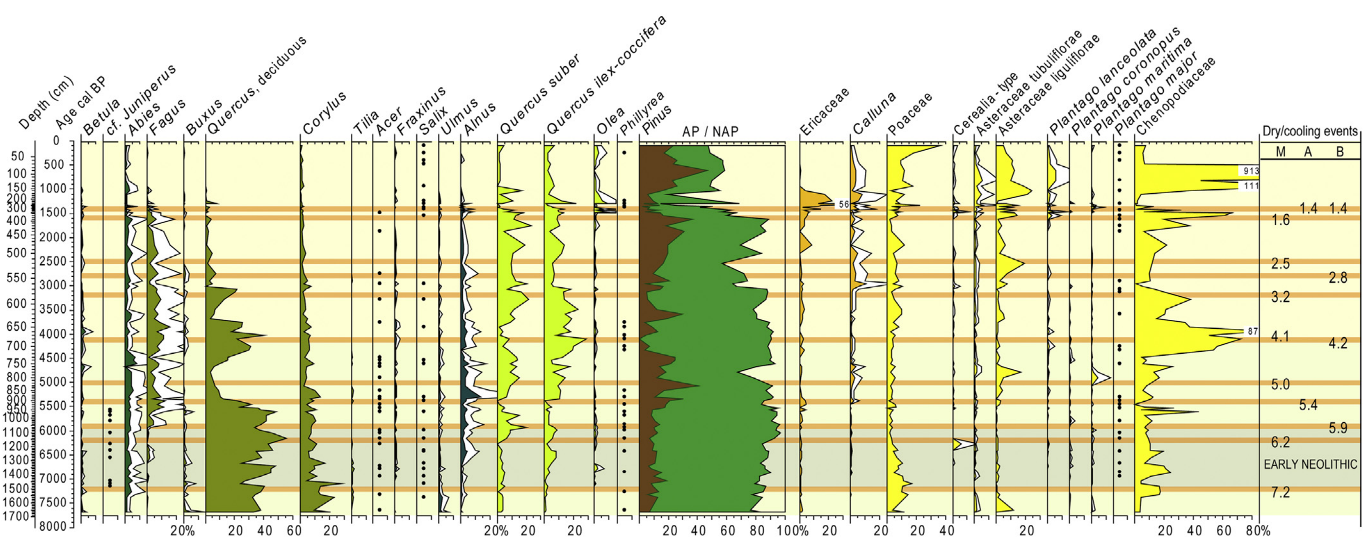

Fig. 8. Percentage pollen diagram. Selected pollen taxa from Sobrestany (Torroella de Montgrí) are plotted to a calibrated year BP scale.

4.2.6. Cova de l'Avellaner (early Neolithic, 6.9–6.4 kyr cal. BP)

In Cova de l'Avellaner (Ros 1990), the dominant taxa are *Buxus sempervirens* and *Corylus avellana*. In this case *Quercus* sp. deciduous is the third taxa according to the number of fragments. The presence of Mediterranean taxa, *Quercus ilex-coccifera* and *Erica* is also documented. Finally, the presence of *Taxus baccata* deserves a special mention.

4.2.7. Cova d'en Pau (early Neolithic, 6.9–6.4 kyr cal. BP)

The predominant taxon is *Quercus* sp. deciduous although *Buxus sempervirens*, Rosaceae/Maloideae and *Acer* sp. are also present (Tarrús and Bosch, 1990). The riparian taxa are represented here by *Corylus*, *Fraxinus*, Salicaceae and *Ulmus*. Quercus *ilex-coccifera* is the only Mediterranean taxa documented by just a few fragments.

4.2.8. Cova 120 (early Neolithic, ca. 6.9–6.1 kyr cal. BP)

Cova 120 (Layer III) has provided the higher diversity of taxa (16); and among them *Juniper* is the best represented (Agustí et al., 1987). Although *Quercus* sp. deciduous has provided abundant remains, the importance of shrubs (*Buxus*, *Phillyrea/Rhamnus*, Rosaceae/Maloideae, *Arbutus*, *Cornus*, *Corylus*), riparian taxa (*Ulmus*, *Laurus*), conifers (*Abies*, *Juniperus*, *Pinus* t. *sylvestris-nigra* and *Taxus*) and other deciduous taxa (*Betula* sp.) is noteworthy.

4.2.9. La Dou (early Neolithic, 6.6–6.2 kyr cal. BP)

The most significant feature of La Dou charcoal record is the low diversity of taxa documented. Among them *Quercus* sp. deciduous, *Buxus sempervirens* and Rosaceae/Maloideae are dominant (Piqué et al., 2017). Conifers are represented by *Pinus* and *Taxus baccata*

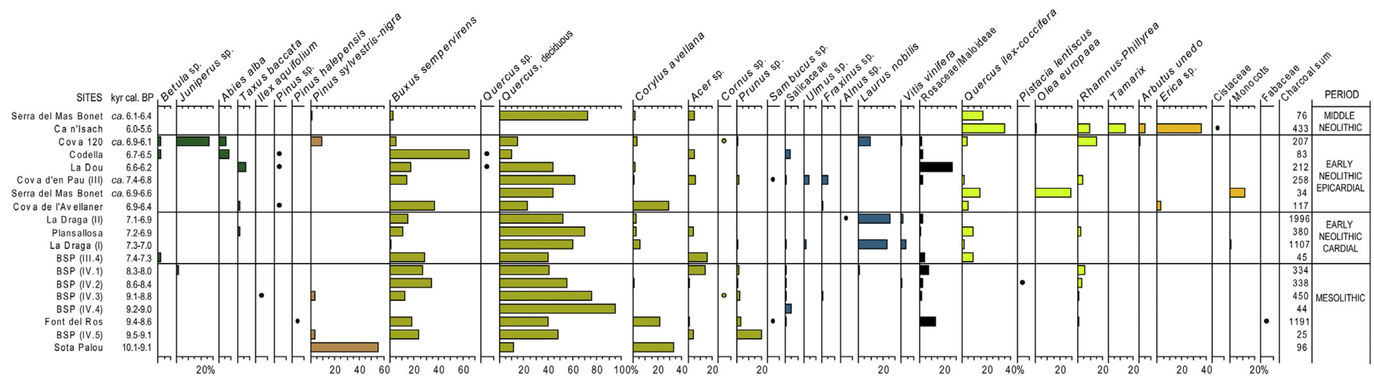

Fig. 9. Anthracology diagram. Sites are ordered by chronology, from Mesolithic to middle Neolithic, the oldest at the bottom and the youngest at the top.

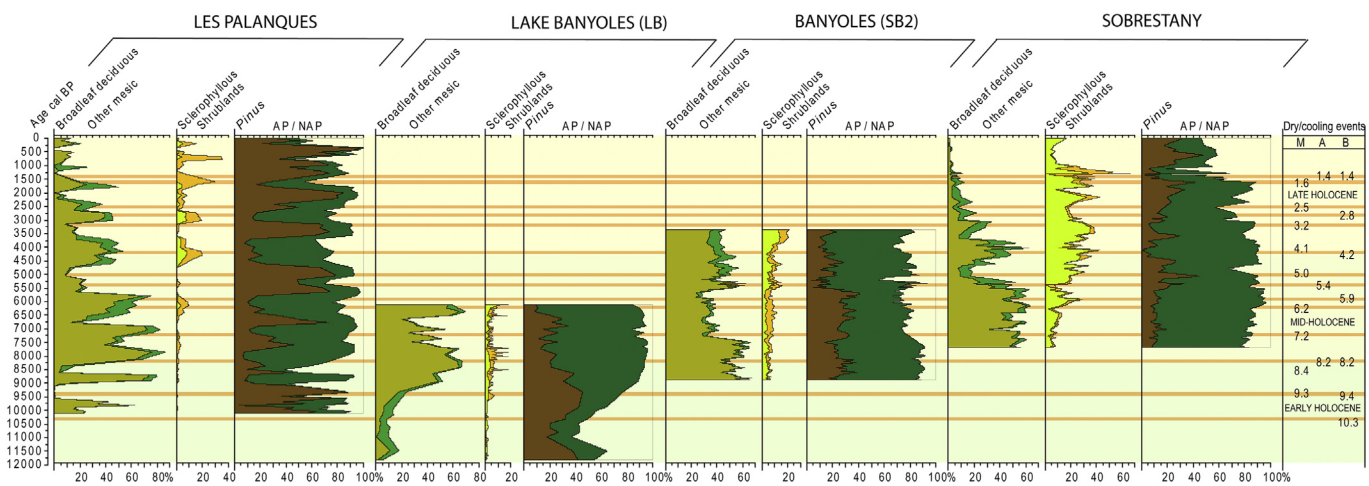

Fig. 10. Synthetic pollen diagram showing the four pollen records included in this study and dry/cooling episodes during the Holocene. Dry/cooling events are plotted (M: Minorca events, Frigola et al., 2007; A: Alboran events, Cacho et al., 2001; B: Bond events, Bond et al., 1997, 2001). Pollen categories: broadleaf deciduous (*Quercus* dec., *Corylus*), other mesic (*Acer, Tilia, Fagus, Ulmus, Fraxinus, Alnus*), Sclerophyllous (*Quercus ilex-coccifera, Olea, Phyllirea, Quercus suber*), Shrublands (*Erica, Ephedra*, Cistaceae, *Rhamnus, Crataegus, Calluna*).

and only one riparian taxon (*Corylus*) has been documented.

4.2.10. Codella (early Neolithic, 6.7–6.5 kyr cal. BP)

The site of Codella is characterized by the dominance of *Buxus sempervirens*, although *Acer* sp., *Quercus* sp. deciduous and Rosaceae/Maloideae are also present (Piqué et al., 2017).

4.2.11. Serra del Mas Bonet (early Neolithic, ca.6.9–6.6 kyr cal. BP; middle Neolithic, ca. 6.1–5.4 kyr cal. BP)

The early Neolithic remains at Serra de Mas Bonet are very scarce, and only four taxa have been documented: Monocots, *Olea europaea*, *Quercus* sp. evergreen and *Quercus* sp. deciduous. However, the middle Neolithic structures have provided a more diverse composition where six taxa have been identified: both deciduous and evergreen *Quercus* are the best represented, and other taxa have a minor presence: *Acer* sp, *Buxus sempervirens* and *Corylus avellana*. The only conifer identified is *Pinus* t. *sylvestris/nigra*.

4.2.12. Ca n'Isach (middle Neolithic, 6.0–5.6 kyr cal. BP)

The charcoal sample from the open air site of Ca n'Isach is characterized by the presence of thermo-mesomediterranean taxa. Only seven taxa have been identified (Ros, 1996); among them *Erica* sp. and *Quercus* sp. evergreen are the most abundant (67% of the identified remains). Other taxa identified are *Olea europaea, Arbutus unedo*, Cistaceae, and *Rhamnus/Phillyrea*. The presence of *Tamarix* sp., a riparian taxa adapted to salty soils, is equally noteworthy.

5. Discussions

5.1. Holocene vegetation history and climate change in the Eastern Pre-Pyrenees

5.1.1. The nature-dominated landscape during the Early Holocene-Late Mesolithic

Human-environment interaction during the Mesolithic cannot be assessed due to scarce evidence of settlement in NE Iberia in this period. However, no direct relationship between climate change and this gap in human settlement dynamics can be established. The archaeological data available for the study area indicate a chronological hiatus of about 400–500 years, in approximately 8100–7600 cal.BP, when no evidence of human occupations attributable to Mesolithic hunter-gatherers has been found (Barceló, 2008; Vaquero and García-Argüelles, 2009; Morales et al., 2013; Oms et al., 2017). The start of this hiatus coincides with the 8.2 kyr cal. BP event, characterized by a time of greater aridity and lower temperatures. According to the available dates, it seems that a population gap occurred after this climate event, and this phenomenon is not exclusive to the study area or north-east Iberia as a whole. On a wider scale, it has been interpreted as the result of human depopulation in some areas prior to the appearance of the Neolithic way of life (Merkyte, 2003; Estévez, 2005; Weninger et al., 2006). Similarly, processes of migration of human communities in search of more appropriate regions have been proposed in the Ebro

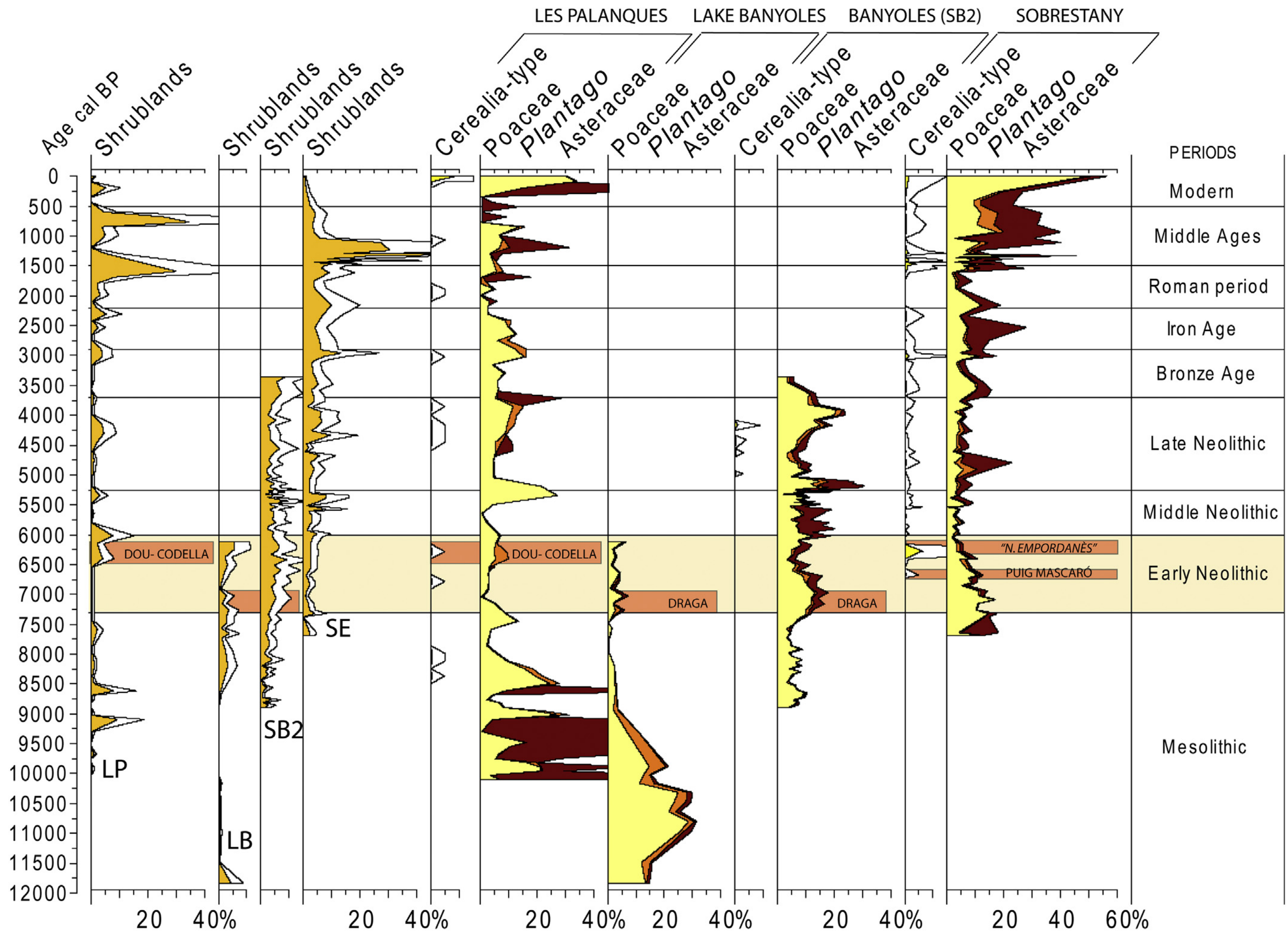

Fig. 11. Synthetic pollen diagram showing NAP and evidence of human impact in the four pollen records included in this study. Abbreviations in shrublands curves: LP (Les Palanques), LB (Lake Banyoles), SE (Sobrestany).

valley (González-Sampériz et al., 2009; García-Martínez de Lagrán et al., 2016).

The expansion of forests in the Early Holocene is well represented in Lake Banyoles, where *Pinus*, *Betula* and *Acer* (low values of mesic trees, below 20% until *ca.* 9.0 kyr cal. BP) played the leading role in this first expansion of woodlands between 11.7 and 9.5 kyr cal. BP. After 9.5–9.0 kyr cal. BP this process was consolidated, reaching 90% of AP at the expense of the grasslands (Poaceae, *Artemisia*) that had formed the Late Glacial steppes, with the dominance of deciduous *Quercus* and *Corylus*, a process attested in other areas of the Iberian Peninsula (Carrion et al., 2010; González-Sampériz et al., 2016). In Les Palanques core (vall d'en Bas), the persistence of high values of Asteraceae and *Artemisia* is also observed during the first millennia of the Early Holocene (in part over-represented by soil erosion and edaphisation in cooling episodes). AP values were low (45–50%) in the period 10.0–9.0 kyr cal. BP. The highest values of *Betula*, *Juniperus* and *Acer* are also significant in this sequence during the Early Holocene, although broadleaf deciduous trees were dominant from the Early Holocene, with higher values of *Corylus* until *ca.* 7.0 kyr cal. BP. This shows the rapid change in humidity and temperature after the Late Glacial in humid Mediterranean areas, as recorded in nearby Atlantic-influenced areas like the Central Pyrenees (González-Sampériz et al., 2005, 2006; Gil-Romera et al., 2014).

Although the presence of taxa in archaeological sites is the result of a human activity they provide significant data about the landscape composition and about its transformation. Several studies have demonstrated their value as a palaeo-environmental proxy, as the combination of pollen and charcoal data provides a more detailed picture of woodland history, landscapes change and wood resource uses (Nelle et al., 2010; Carrion et al., 2010). The results of charcoal studies show the importance of *Pinus* t. *sylvestris-nigra* during the Early Holocene, which is well represented in Sota Palou (10.2–9.1 kyr cal. BP). However, the charcoal at the sites of Sota Palou and Font del Ros (9.4–8.6 kyr cal. BP) also show the expansion of *Corylus avellana* and *Quercus* sp. deciduous in the region during this time. The importance of *Quercus* sp deciduous is confirmed also by its presence in Level IV.5 at La Bauma del Serrat del Pont (9.4–9.1 kyr cal. BP).

Strong falls in values of broadleaf deciduous trees and also of AP at Les Palanques (Vall d'en Bas), as well as peaks in *Pinus*, shrublands and grasslands (at 711–761 cm and 652–682 cm; *ca.* 9.5–9.0 kyr cal. BP and in *ca.* 8.6–8.3 kyr cal. BP, respectively), is associated with changes in sedimentation (from organic clays to clayish silts), probably linked with edaphisation or erosion processes (Pérez-Obiol, 1988). These processes could have been linked with cooling events in 9.4 kyr cal. BP and 8.2 kyr cal. BP (Bond et al., 1997, 2001), global events also recorded in the Mediterranean Sea (Cacho et al., 2001; Frigola et al., 2007) and in Iberian lacustrine records (Carrión, 2002; González-Sampériz et al., 2006; Vegas et al.,

2009; Pérez-Sanz et al., 2013). Charcoal data from Bauma del Serrat del Pont have provided the highest frequencies of *Quercus* sp. deciduous in the region in 9242–8775 cal BP (Levels IV.4 and IV.3) although its use decreased significantly in the last Mesolithic levels (IV.2 and IV.1) dated at 8632-8021 cal BP. This decrease in oak consumption coincides with the slight regression of broadleaf deciduous trees observed in the pollen record (Figs. 5 and 10) in the context of the 8.2 kyr cal. BP cooling event. The decrease of *Quercus* deciduous is contemporaneous to the increase in other taxa like *Buxus sempervirens*, poorly represented in the pollen record, *Acer* sp. and *Pinus sylvestris,* although the presence of the latter does not reaches the previous values.

In the Lake Banyoles area, slight mesophilous taxa regressions occurred in the 8.2 cal ka BP event in both records (LB and SB2), but these amounted to minimal declines in the total AP and a slight increase in shrubs or grasslands (Poaceae, Asteraceae) (Fig. 11). This situation shows once more that this cooling phenomenon would correspond with a wetter climate in European middle latitudes, locating the southern limit about 38–40° N (central Iberian Peninsula) (Magny et al., 2003, 2013).

5.1.2. Mid-Holocene vegetation history and the first signs of Neolithic human impact

Broadleaf deciduous forests in the Lake Banyoles area reached their maximum expansion in the phase 9.0–7.5 kyr cal. BP, followed by a decline in 7.5–6.5/5.5 kyr cal. BP, but a recovery afterwards, showing persistence of oak forests as the dominant vegetation until the onset of the Late Holocene, at the end of the SB2 sequence (3.35 kyr cal. BP). Therefore, despite a decreasing trend from 7.5 kyr cal. BP onwards, broadleaf deciduous forests resisted against cooling oscillations during the Middle Holocene. The cooling phase in 7.2 kyr cal. BP would have been important, but the regression of deciduous forests should also be understood in the context of the arrival of the first farming societies into the area in 7.27 kyr cal. BP (Palomo et al., 2014). Although cooling events detected in the Minorcan Sea in 5.0 and 4.1 kyr cal. BP (Frigola et al., 2007) coincide with phases of slight regressions of oak forests in the SB2 sequence, these cooling episodes did not cause irreversible changes and forests rapidly recovered, showing the resilience of deciduous broadleaf forests against climate change in this region.

The charcoal records in the first farming settlements in the region are characterized by the dominance of *Quercus* sp. deciduous associated with *Buxus sempervirens*. However, other taxa are also important in some sites and chronologies. *Laurus nobilis* is especially important at La Draga, probably due to the proximity of Lake Banyoles and *Corylus avellana* is well documented at la Cova de l'Avellaner. Local availability is without doubt one of the reasons of the taxa variability, although the specific function of the sites should be considered. The presence of *Quercus ilex* should also be mentioned, given that this taxon is recurrently present albeit in low frequencies from the early Neolithic levels. Other Mediterranean taxa like *Arbutus* and *Erica* have also been documented, showing the availability of Mediterranean sclerophyllous vegetation in the region despite being in the minority in pollen records. Nevertheless, sclerophyllous vegetation is not so represented in charcoal records as it is in southern coastal areas in NE Iberia (i.e. Barcelona, Allué et al., 2017). Finally the presence of *Taxus baccata* in early Neolithic chronologies is noteworthy, showing that this taxon was present in the surroundings despite its low visibility in pollen records.

On the coast, the Sobrestany sequence shows a maximum expansion of broadleaf deciduous forests in 7.7–5.6 kyr cal. BP with declines in 7.3–6.4 kyr cal. BP and in *ca*. 5.9 kyr cal. BP (Fig. 8). Nevertheless, the expansion of evergreen *Quercus* and the appearance of a continuous curve of *Fagus* led to the maximum values of AP (over 90%) in the sequence in the period 6.1–5.7 kyr cal. BP. A decline of deciduous *Quercus* and *Corylus* and the dominance of evergreen sclerophyllous forests over broadleaf deciduous forests occurred after 5.5 kyr cal. BP.

The only charcoal data available for the early Neolithic in Empordà is the site of Serra del Mas Bonet. The site has only provided a small sample of charcoal and only four taxa have been documented. Although deciduous *Quercus* is dominant, the presence of Mediterranean taxa is noteworthy: evergreen *Quercus* and *Olea europaea*. This evidence, together with noticeable values of *Olea* in Sobrestany sequence (Fig. 7) indicates that aridity increased earlier on the coast than in Banyoles and la Garrotxa. The results obtained confirm the role of Mediterranean taxa in this region during the middle Holocene. Later, in the middle Neolithic the occupations at Serra del Mas Bonet and Ca n'Isach show a diverse landscape; deciduous taxa still play an important role at the first, but Mediterranean sclerophyllous vegetation is dominant at the second.

Despite some cooling episodes punctuating the relatively stable Holocene climate, broadleaf deciduous woodland persisted as the dominant vegetation during the middle Holocene in the Eastern Pre-Pyrenees (Fig. 10). The cooling phase documented in the Minorcan Sea records (Frigola et al., 2007) in 7.4–6.9 kyr cal. BP, with the central age in 7.2 kyr cal. BP, should be noted, due to the coeval broadleaf deciduous forest regressions in the whole area (Fig. 10). Although human impact associated with the adoption of farming and the establishment of more permanent settlements should also be considered to comprehend these changes in vegetation; it seems that the Neolithisation process in the Iberian Peninsula must have occurred in the context of a cooler and drier climate. In that sense, this cooling phase, reflected by the synchrony of mesophilous taxa regression in the whole transect (Fig. 10), would have amplified the imprint of the impact of the first farming societies.

In that sense, despite the regression of mesophilous taxa in some Mid-Holocene cooling episodes, persistence of deciduous forests is observed in the area until the Late Holocene. The change in seasonality, with a longer dry season and lower precipitation and water availability in summer, which occurred in the transition to the Late Holocene (5.0–4.0 kyr cal. BP), provoked changes in vegetation that explain the current landscape in this region, with the replacement of broadleaf deciduous woodland by evergreen sclerophyllous forests and shrublands in a progressively more open landscape.

5.2. Landscape transformation during the Early Neolithic

Occupations corresponding to early Neolithic are documented after the Mesolithic hiatus in the archaeological record. Radiocarbon dates seem to show that the first evidence attributable to the Neolithic appeared in central and southern parts of Catalonia around 7500 cal. BP, coinciding with the spread of *impressa* ware from Liguria and Languedoc. In the study area, the first dates attributed to the Neolithic are situated in 7.3–7.0 kyr cal. BP. They correspond to the Cardial Neolithic phase, at sites in which the distinctive traits of Neolithic subsistence were firmly installed. At this time, a clear contrast can be seen between quite large settlements, with a well-established farming economy, exercising considerable influence in the terrain, and the sites in inland valleys, mostly in caves and rock-shelters, of lesser importance and where subsistence was complemented by wild resources. The relationship between these two types of sites in the same area has not been researched to any great extent. However, it is possible that they correspond to different degrees of consolidation of the farming economy in the area, although both models may have been

complementary and supported one another.

In that context, from 7.4 kyr cal. BP onwards, evidence of human impact has been recorded in the Eastern Pre-Pyrenees region, specifically in the Lake Banyoles area. Pollen records from Lake Banyoles show coeval expansions of shrublands after 7.3 kyr cal. BP (peak in 7.3 kyr cal. BP and an increasing trend from 6.8 to 6.1 kyr cal. BP in LB; and increase in 7.3–6.4 kyr cal. BP in SB2), an expansion of grasslands (Fig. 11) and regression of oak forests after 7.5–7.3 kyr cal. BP. Although a cooler climate would have affected the development of broadleaf deciduous trees, these changes in vegetation have to be understood in the context of the arrival of the first farming societies in the area. In that sense, early Neolithic communities settled the eastern lakeshore in the settlement of La Draga, where two different phases of early Neolithic occupation have been documented, dated in 7270–6750 yr cal. BP (Palomo et al., 2014). From a more regional perspective, there is other evidence of early Neolithic occupation in Serinyà Caves (4–5 km away from Lake Banyoles) and Esponellà Caves (10 km away). Nevertheless, no evidence of Cerealia-t has been documented in this phase, due to the limited impact of the intensive agriculture practiced during the Early Neolithic (Antolín et al., 2014, 2015; Revelles et al., 2014, 2015). The first evidence of agricultural impact in pollen records is documented in the Late Neolithic, when evidence of local cultivation in the lakeshore is recorded in SB2 core.

From 7.0 kyr cal. BP onwards first farming societies spread across the whole area (Fig. 3), from the coast following water-courses upriver, as far as the Pyrenean valleys (Gassiot et al., 2014). In this process, greater specialisation is seen in the occupation of the different sites, with some used for typical activities at habitation sites. However, the duality between large open-air sites and smaller occupations in caves and rock-shelters appears to have continued. Caves were used for specific purposes (as animal pens, to store agricultural produce, or for burials) that may have occasionally complemented the everyday activities in the settlements.

In Vall d'en Bas, the decline in the oak forest at 528–545 cm (*ca.* 6.8–6.6 kyr cal. BP) coincides with a peak in *Pinus* and the presence of Cerealia-t. In that context, the establishment of the first farming communities in the valley, at the sites of Codella (6660-6520 yr cal BP; Alcalde et al., 2009) and La Dou (6560-6213 yr cal BP; Alcalde et al., 2012, 2014) could have caused the increase in Poaceae, a peak in *Plantago* and presence of Cerealia-t (Fig. 11). On the coast, in the Empordà basin, a regression of broadleaf deciduous forests and a decline in AP coincides with peaks of Poaceae in 7.35–7.1 kyr cal. BP. It is difficult to attribute an anthropogenic cause to this change, given the scarcity of Early Neolithic Cardial remains in the Empordà plain (Turó de les Corts and Cau de les Guilles, 10 and 23 km away, respectively), and it was probably linked to climate (cooling phase in 7.4–6.9 kyr cal. BP; Frigola et al., 2007). The first Neolithic impact is documented in 6.7–6.6 kyr cal. BP with a peak of Poaceae and presence of Cerealia-t and a decline in deciduous *Quercus* and in 6.4–6.3 kyr cal. BP with a slight increase in Poaceae, presence of *Plantago lanceolata* and *P. coronopus* (Fig. 8) and high values of Cerealia-t. This is consistent with archaeological data in the area, where Neolithic evidence is attested in deposits bearing pottery in the "Epicardial" style, dated in the period 6.9–6.6 kyr cal. BP (Table 1), such as Puig Mascaró (Torroella de Montgrí, Baix Empordà) (Pons and Tarrús, 1980) or Serra del Mas Bonet (Vilafant, Alt Empordà) (Rosillo et al., 2009, 2012). The expansion of the settlement in the Empordà region occurred in the transition to the Middle Neolithic, the so-called "Neolític Empordanès", from 6.1 kyr cal. BP onwards with new occupations in Serra del Mas Bonet, Camí dels Banys de la Mercè, and the new settlement of Ca n'Isach (Tarrús et al., 1992) (Fig. 3).

When comparing between areas, we can observe a longer and more intensive human impact in Pla de l'Estany, shown in the oak forest clearance maintenance between 7.25 and 5.55 kyr cal. BP, indicating long intensive exploitation of the landscape in the Early Neolithic period. Thus is probably due to the earlier occupation of this region, the only one attesting the first Cardial Early Neolithic (7.35–6.95 kyr cal. BP) and the role of La Draga as a large settlement exercising a remarkable influence on the territory. In the early Neolithic of the Lake Banyoles area the great human impact documented was mainly caused by the exploitation of forests to provide oak timber for construction (Revelles et al., 2014), and therefore different constructive traditions in later periods and in different geographic areas could have resulted in a smaller human imprint in the landscape. In Lake Banyoles, the exceptionality of La Draga allowed the comparison of vegetation changes in the pollen record (oak forest regression) with evidence of use of oak timber in huts construction (around 1000 oak trunks in 800 m^2 excavated, Revelles et al., 2014). However, in other Iberian Neolithic settlements this cannot be assessed, given the fact that archaeological structures consist of negative contexts (cuts) or accumulation of stones, and the raw material of huts, like timber, cannot be inferred. In any case, it is evidenced that early Neolithic agriculture did not involve a great impact in the landscape, with short episodes of forest regression and clearances in oak forests, but always followed by rapid recoveries. The charcoal record in early Neolithic sites shows the intensive exploitation of deciduous forests. However, although deciduous *Quercus* is the best represented taxon in the earliest occupations in open-air sites (La Draga phase I, Plansallosa, *ca.*7300–6900), secondary taxa such as *Buxus sempervirens* would have expanded in degraded oak forests, as attested at La Draga phase II (Caruso-Fermé and Piqué, 2014) and lower values of arboreal taxa are documented in settlements from 7.0 to 6.0 kyr cal. BP onwards. This would have been the result of the impact of the human activity on vegetation at local level.

It was the sedentary lifestyle, the permanent and continuous human pressure on the territory causing landscape transformation, which explains differences between areas, depending on the scale and duration of settlements. In that sense, it seems that Pla de l'Estany was the area most intensively occupied during the Early Neolithic. In Vall d'en Bas, Neolithic settlement would have occurred later and been less continuous in time, with occupations in the phase 6700-6200 yr cal. BP, but without evidence of later occupation until the Late Neolithic, in La Prunera (5300-4875 yr cal. BP). Despite the nearby Llierca valley being continuously occupied during Late Prehistory, the topography of the area, with orographic barriers between both valleys would have resulted in the fact that the impact of Vall del Llierca communities was not reflected in Vall d'en Bas pollen records. On the other hand, in Pla de l'Estany, although there are not many C^{14} dates for the Neolithic (only at La Draga), there is abundant evidence of occupation in Serinyà and Esponellà Caves during the whole of Late Prehistory, without gaps, as well as Late Neolithic evidence on the western shore of Lake Banyoles, in Santa Maria de Porqueres. Additionally, the topography and the characteristics of the basin and the pollen catchment area would have influenced the difference between regions. In that sense, the plain of the Lake Banyoles area, without topographic barriers, provides pollen records showing regional signals. Pollen records from Vall d'en Bas would only provide information for the valley, constituting a more local deposit in terms of pollen record representation. In the case of the Empordà basin, there is scarce evidence of early Cardial Neolithic (Cau de les Guilles and Turó de les Corts) and more evidence of settlements appear after 7.0 kyr cal. BP and even later in the Middle and Late Neolithic (i.e. Serra del Mas Bonet, Ca n'Isach, Riera Masarac, Mas Baleta). Indeed, at a local scale, wetlands on the Empordà coast would not have been a suitable area for Neolithic occupations, and the settlements are located on the inland floodplain and low hills. The impact of

agriculture is occasionally observed during short periods that lasted no more than 200 years and did not affect the capacity of forests to recover (Parra et al., 2005). The wetlands area would not be occupied until recent chronologies.

6. Conclusions

Climate and human impact influenced environmental changes in the Mid-Holocene. The landscape was mostly controlled by climate change until the Neolithic (from 7.4 to 7.0 kyr cal. BP onwards), when human impact started to interfere in the natural development of vegetation. However, the Neolithisation of the Iberian Peninsula occurred in a cooling episode that amplified the effect of the human impact of the first farming societies. The interaction between the cooling phase in 7.4–6.9 kyr cal. BP and the first farmers has mainly been documented in the Lake Banyoles area, where earlier Neolithic evidence is also documented. In the other two regions, the Neolithic communities settled later, after 6.7 kyr cal. BP in Vall d'en Bas and in 6.9–6.6 kyr cal. BP in the Empordà basin. Anyway, anthropogenic modifications of landscape were sustainable until recent times. In that sense, the interaction between Mid-Holocene cooling episodes and human impact transformed the landscape causing regression of broadleaf deciduous forests, but this was followed by rapid recoveries when human pressure finished (e.g. in SB2 in 5.55 kyr cal. BP or in 6.2 kyr cal. BP in Sobrestany).

The impact of some cooling events in the Eastern Pre-Pyrenean region is evidenced both in the sub-Mediterranean interior and in Mediterranean littoral areas. The change in seasonality, with a longer dry season and lower precipitation and water availability in summer, which occurred in the transition to the Late Holocene (5.0–4.0 kyr cal. BP), started the decline of broadleaf deciduous forests in coastal areas. The consolidation of this process occurred in the Late Holocene (3.5–3.0 kyr cal. BP) and, for instance, this study shows that the process of replacement of broadleaf deciduous by sclerophyllous forests was not always homogeneous, and sub-Mediterranean climate areas showed the resilience of broadleaf deciduous woodland until the Late Holocene, as on the northern shores of the central Mediterranean. The most important cooling phases in this area during the Middle Holocene were the 8.2 kyr cal. BP event, causing a slight regression of broadleaf deciduous woodland; the 7.2 kyr cal. BP event, when a cooling episode enlarged the fingerprint of Neolithic human impact; and in 5.0 kyr cal. BP, when mesophilous taxa declined significantly, especially in Vall d'en Bas and in the Empordà basin. Nevertheless, the evidence of a minor impact of the 8.2 kyr cal. BP event do not explain the hiatus of settlements during Late Mesolithic in the area, and complementary or alternative hypothesis should be considered in future research.

Future palaeoecological research in the NE Iberian Peninsula should complete this scenario, integrating multi-proxy analysis, which is lacking in some of the sequences presented in this paper. In addition, the study of new cores in similar climatic and/or archaeological contexts will surely provide a better palaeoenvironmental and geochronological knowledge of the processes and dynamics discussed in this work. In addition, the integration of sedimentary charcoal analysis is essential in this respect and in this setting, given that fire should be considered an inherent element in the Mediterranean environment (Vannière et al., 2008) and also that fire is connected to climate change but also to human activities.

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